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Cassini discovers seasonal changes in Rhea's exosphere

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1. Introduction

We present new measurements of Rhea's O_2 - CO_2 exosphere from Cassini's 11 January 2011 south polar flyby revealing time variability in the gas density and distribution at this Saturnian icy satellite (Figs. 1-2). The existence of an exosphere; first suggested by Cassini Plasma Spectrometer observations of outflowing pickup ions, was recently confirmed by in situ measurements from the Ion Neutral Mass Spectrometer (INMS) during Cassini's 2 March 2010 north polar flyby [1]. Like the Galilean moons Europa and Ganymede [2], Rhea's O_2 is a chemical decomposition product of the surface ice due to irradiation by Saturn's magnetospheric plasma. Exospheric CO_2 may be (i) synthesized from radiolysis involving surface-bound oxygen and endogenic and/or implanted organics, and/or (ii) may be due to escape of primordial CO_2 from the ice.

2. 2011 Flyby Results

Compared to the 2010 north polar flyby, the INMS observed less O_2 in the south during the 2011 encounter, and failed to detect CO_2. A crucial difference between these flybys is the solar inclination. The 2010 pass occurred in northern spring, 7 months after equinox in August 2009, while by contrast, the south pole had not been subject to solar illumination for 17 months as of the 2011 encounter. The 2010 measurements showed a highly asymmetrical carbon dioxide distribution, with most of the CO_2 localized over the warmer dayside hemisphere; suggesting that gaseous CO_2 readily freezes onto the colder night-side surface, as expected at these surface temperatures (~40–50 K on the night-side [3]). Likewise, the lack of CO_2 during the 2011 flyby is consistent with adsorption onto the southern surface, which was likely several degrees K colder (possibly ~40 K [3] or below) in 2011 than 2010. However, in contrast to lower latitudes where adsorbed CO_2 may be re-released as the advancing dawn terminator re-heats the surface every 4.5 (earth) days, polar CO_2 is trapped for much longer periods, analogous to lunar volatiles [4]. Therefore the south polar region (or, conversely the north polar region, during northern winter) may act as a semi-permanent cryotrap for CO_2 which lowers the CO_2 densities globally, but quantitative estimates of this effect will require additional modeling.

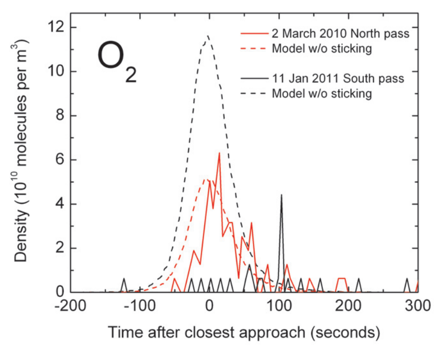

Figure 1: The O_2 density vs. time measured by INMS during the 2010 and 2011 Rhea encounters, compared to a model which does not assume surface adsorption.

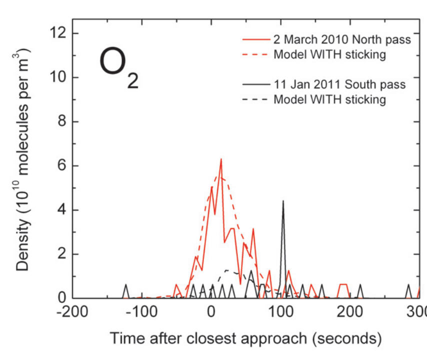

Figure 2: Same as Fig. 1, but with the assumption of surface O_2 adsorption.

3. Molecular Oxygen Sticking

Molecular oxygen is much more volatile than CO_2 [1], and therefore our modeling prior to the 2011 flyby, which assumed no surface adsorption, predicted 2011 along-track O_2 densities exceeding those of the 2010 encounter due to the lower flyby altitude. Thus the finding of *less* O_2 in the south suggests that in fact the surfaces are sufficiently cold to condense O_2. In Figs. 1 - 4 we show the results of a Monte Carlo model of the O_2 exosphere for the 2010 and 2011 encounters, with and without surface adsorption. The model initialized molecules according to the expected position-dependent distribution of radiolysis (concentrated on the trailing hemisphere [1]), assumed random ballistic trajectories between surface impacts, thermally equilibrated re-impacting molecules with the surface by reinitializing the speed with a Maxwell-Boltzmann distribution at the local surface temperature [3], and destroyed the molecules in mid-flight according to the loss rate from pickup ionization (a fitting parameter of the simulation) or on leaving the Hill sphere. The assumption of surface (temperature-dependent) adsorption produces a small improvement of the fit to the 2010 measurement over the night side (Fig. 2); a result which had already implied a possibility of night-side O_2 sticking [1]. However, while without adsorption the model drastically over-estimates the 2011 O_2 measurement, the assumption of adsorption yields a good fit, and can explain (i) the low O_2 density encountered and (ii) the shift in the O_2 signal to the outbound portion of Cassini's trajectory (Figs. 2 and 4). In addition to the highly inhomogeneous gas distribution around the satellite, the inclusion of adsorption also lowers the atmospheric density globally (Fig. 4), since some O_2 adsorbed near the south pole can be trapped for long periods. We note that the sticking times required in the model (e.g., on the order of years at 40 K) are much greater than the times (e.g., 40 milliseconds at 40 K) given by the (smooth) surface O_2 binding energy of 0.095 eV [5], which implies enhanced cryotrapping due to percolation and multiple collisions of O_2 at depth within the ice regolith.

Acknowledgements

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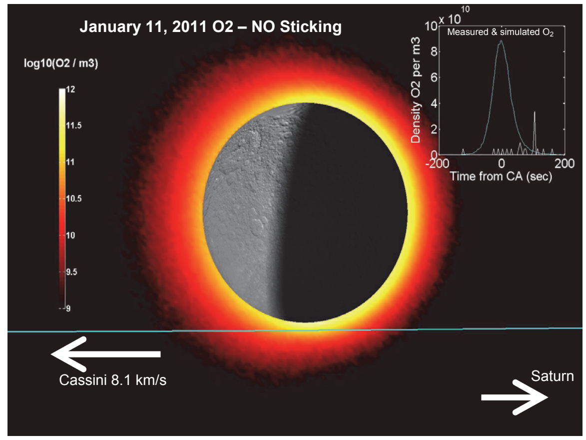

Figure 3: A cross section of the 2011 flyby model atmosphere used in Fig. 1 which does not include sticking.

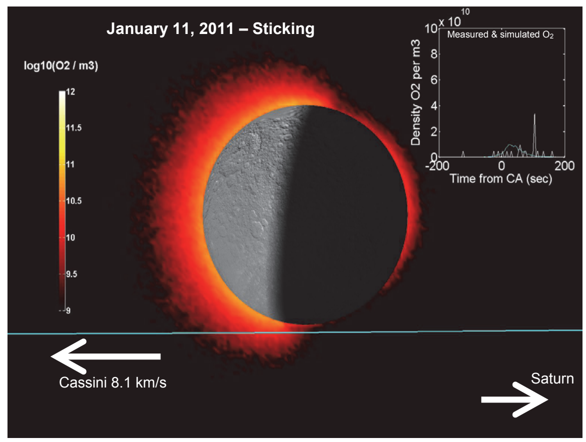

Figure 4: Model used in Fig. 2 which does include sticking.

References

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